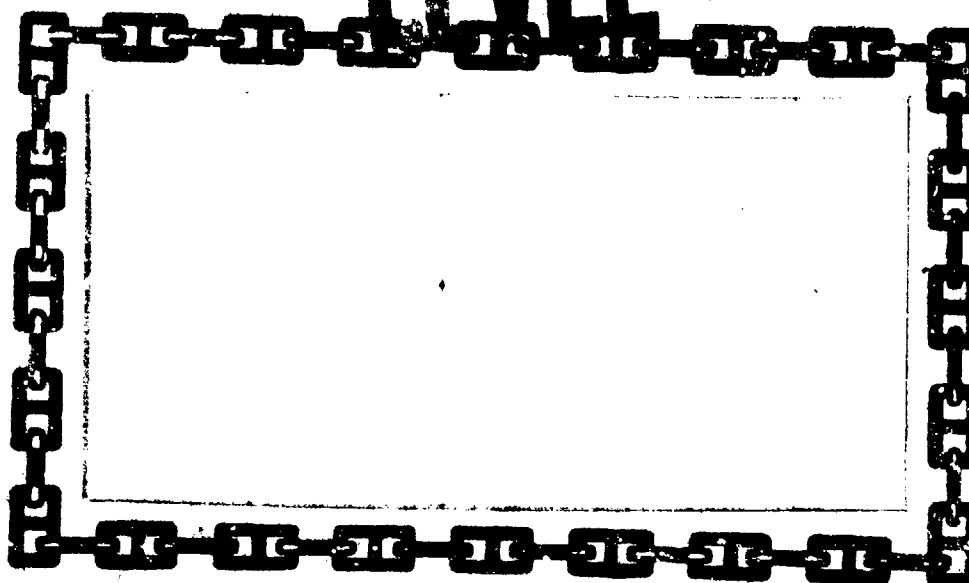


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NAVY EXPERIMENTAL DIVING UNIT  
REPORT NO. 5-79  
EVALUATION OF MODIFIED DRAEGER LAR V  
CLOSED-CIRCUIT OXYGEN REBREATHING  
PART I: UNMANNED TESTING  
JAMES R. MIDDLETON  
PART II: MANNED TESTING  
CLAUDE A. PIANTADOSI  
August 1979

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19. ABSTRACT (Continue on reverse side if necessary and identify by block number) The modified Draeger LAR V closed-circuit oxygen rebreather was evaluated by the Navy Experimental Diving Unit to determine its suitability for U.S. Navy use. Previous evaluation of the German-made scuba in its standard configuration found the LAR V technically satisfactory with adequate reliability and maintainability characteristics; however, the clockwise oxygen flow in the breathing loop is the reverse of all U.S. Navy scuba equipment. The manufacturer modified 10 units for further NEDU testing. Unmanned CO <sub>2</sub> (CONT)		

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canister duration tests resulted in canister breakthrough after 48 minutes in cold (39°F [4°C]) water and 3 hours 15 minutes in warm (70°F [21°C]) water. LAR V breathing resistance values at light, moderate, heavy and extreme diver work rates were acceptable.

In view of the short unmanned canister durations experienced in cold water, a series of 24 manned dives was carried out in the OSF wet pot at 25 FSW in 70°F (21°C) and 40°F (4°C) water. Canister outlet carbon dioxide levels, breathing resistance, and oxygen consumptions were measured. Mean canister duration was  $226 \pm 23$  minutes and  $124 \pm 9$  minutes in 70°F (21°C) and 40°F (4°C) water respectively. Breathing resistance was acceptable at all work levels, and no other design limitations were encountered. Differences in unmanned versus manned canister durations in cold water may be partly attributable to slightly higher carbon dioxide injection rates during unmanned testing.

Based upon manned studies at 25 FSW, the LAR V is recommended for Authorized for Navy Use (ANU) status to depths of 25 FSW and time limits specified by figure 19 of this report or as specified in table 13-2 of the U.S. Navy Diving Manual.

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## TABLE OF CONTENTS

	<u>Page</u>
Table of Contents. . . . .	1
Abstract . . . . .	111
Glossary . . . . .	iv
 <u>PART I: UNMANNED TESTING</u>	
INTRODUCTION . . . . .	1
EQUIPMENT DESCRIPTION. . . . .	3
FUNCTIONAL DESCRIPTION . . . . .	3
TEST PROCEDURE . . . . .	
Test Plan . . . . .	5
Controlled Parameters . . . . .	5
Measured Parameters . . . . .	7
Computed Parameters . . . . .	7
Data Plotted. . . . .	7
RESULTS AND DISCUSSION	
Breathing Resistance Test Results . . . . .	8
Canister Differential Pressure. . . . .	14
CO <sub>2</sub> Canister Duration . . . . .	14
CONCLUSIONS AND RECOMMENDATIONS	
Breathing Resistance . . . . .	23
Respiratory Work. . . . .	23
Canister Pressure Drop. . . . .	23
CO <sub>2</sub> Scrubber Breakthrough/Duration Test . . . . .	23
REFERENCES . . . . .	24
APPENDIX A - Test Plan . . . . .	25
APPENDIX B - Test Equipment. . . . .	27

## TABLE OF CONTENTS

(Continued)

	<u>Page</u>
PART II: MANNED TESTING	
INTRODUCTION . . . . .	28
TEST PROCEDURE . . . . .	28
RESULTS AND DISCUSSION . . . . .	30
CONCLUSIONS AND RECOMMENDATIONS. . . . .	32
REFERENCES . . . . .	38

## ABSTRACT

The modified Draeger LAR V closed-circuit oxygen rebreather was evaluated by the Navy Experimental Diving Unit to determine its suitability for U.S. Navy use. Previous evaluation of the German-made scuba in its standard configuration found the LAR V technically satisfactory with adequate reliability and maintainability characteristics; however, the clockwise oxygen flow in the breathing loop is the reverse of all U.S. Navy scuba equipment. The manufacturer modified 10 units for further NEDU testing. Unmanned CO<sub>2</sub> canister duration tests resulted in canister breakthrough after 48 minutes in cold (39°F [4°C]) water and 3 hours 15 minutes in warm (70°F [21°C]) water. LAR V breathing resistance values at light, moderate, heavy and extreme diver work rates were acceptable.

In view of the short unmanned canister durations experienced in cold water, a series of 24 manned dives was carried out in the OSF wet pot at 25 FSW in 70°F (21°C) and 40°F (4°C) water. Canister outlet carbon dioxide levels, breathing resistance, and oxygen consumptions were measured. Mean canister duration was 226 ± 23 minutes and 124 ± 5 minutes in 70°F (21°C) and 40°F (4°C) water respectively. Breathing resistance was acceptable at all work levels, and no other design limitations were encountered. Differences in unmanned versus manned canister durations in cold water may be partly attributable to slightly higher carbon dioxide injection rates during unmanned testing.

Based upon manned studies at 25 FSW, the LAR V is recommended for Authorized for Navy Use (ANU) status to depths of 25 FSW and time limits specified by figure 19 or as specified by table 13-2 of the U.S. Navy Diving Manual.

# GLOSSARY

ANU	Authorized for Navy Use
ata	Atmosphere absolute
BPM	breaths per minute
Canister Breakthrough	point at which CO <sub>2</sub> concentration in the breathing gas reached 0.5 percent surface equivalent
°C	temperature in degrees Centigrade
cm H <sub>2</sub> O	centimeters of water pressure (differential)
CO <sub>2</sub>	carbon dioxide gas
°F	temperature in degrees Fahrenheit
FSW	feet of seawater
FPM	feet per minute
H.P. Soudasorb	high-performance Soudasorb
kg.m/l	breathing work in kilogram meters per liter ventilation
kp/cm <sup>2</sup>	pressure, in kilopound per square centimeters
LTV	liters tidal volume
LPM	liters per minute (flow rate)
NEDU	Navy Experimental Diving Unit, Panama City, Florida
O <sub>2</sub>	oxygen
OSF	Ocean Simulation Facility
ΔP	pressure differential (cm H <sub>2</sub> O)
ppCO <sub>2</sub>	partial pressure of carbon dioxide
ppO <sub>2</sub>	partial pressure of oxygen
psig	pounds per square inch gauge
RMV	respiratory minute volume in liters per minute



## GLOSSARY

(Continued)

S.E.	surface equivalent volume
SLPM	standard liters per minute
tidal volume	volume of air breathed in and out of the lungs during normal respiration
UBA	underwater breathing apparatus

## PART I: UNMANNED TESTING

### INTRODUCTION

In November 1978, the Navy Experimental Diving Unit tested the modified Draeger LAR V closed-circuit pure oxygen scuba manufactured by Draegerwerk, Lubeck, 24 Lubeck, P. O. Box 1139, Moislinger Allee 53/54, Federal Republic of Germany. Previous NEDU evaluation (reference 1) of the standard LAR V found the scuba equal or superior to the U.S. Navy Emerson scuba with respect to its technical characteristics, training and operational use, reliability and maintainability. However, NEDU requested that Draeger modify the scuba to interface more effectively with U.S. Navy equipment, as the standard LAR V breathing loop O<sub>2</sub> flow is clockwise in contrast to the counterclockwise breathing loop flow in U.S. Navy equipment.

Unmanned testing of the modified units measured breathing resistance and CO<sub>2</sub> absorbent canister breakthrough duration at standard U.S. Navy operating depths for pure oxygen scuba.



Figure 1. Draeger LAR V Pure Oxygen UBA

## EQUIPMENT DESCRIPTION

The Draeger LAR V is a closed circuit, pure oxygen scuba providing oxygen through a demand valve or manual bypass valve. A CO<sub>2</sub> absorbent canister (approximately capacity equivalent to 5.95 pounds Baralyme or 5.56 pounds Sodasorb) removes CO<sub>2</sub> from the breathing system.

Fully charged with gas and CO<sub>2</sub> absorbent, the LAR V weighs approximately 25.5 pounds; fully charged and in carrying case, the unit (figure 1) weighs approximately 37 pounds. The LAR V is 16.9 inches long, 11.8 inches wide, and 6.7 inches thick. A belt buckle harness securing the unit to the diver's chest can be rigged for quick disconnect.

Major LAR V components are the equipment case, pneumatic assembly, CO<sub>2</sub> scrubber assembly, and breathing system. (For detailed equipment descriptions, see section 1 of NEDU Report 11-75 [reference 1].)

## FUNCTIONAL DESCRIPTION

The functional description of the Draeger LAR V is illustrated in figure 2. From the oxygen cylinder (1), high-pressure oxygen passes through the cylinder on/off valve (2) to the pressure reducing regulator (3) where the high-pressure gas is reduced to a working pressure of 66-psig over-bottom setting, then piped to the demand regulator (4) which is adjustable from 10 to 30 cm H<sub>2</sub>O. High-pressure gas is also piped to the 0 to 300 kp/cm<sup>2</sup> (0 to 4410 psig) pressure gauge located on top of equipment case housing. The demand regulator, secured to the equipment case housing and fitted to the breathing bag (5), functions each time the bag is emptied on inhalation. On inhalation, the inhalation check valve (6) opens and the diver receives gas from the breathing bag. If not enough gas is available, the demand valve actuates, adding more oxygen to the system.

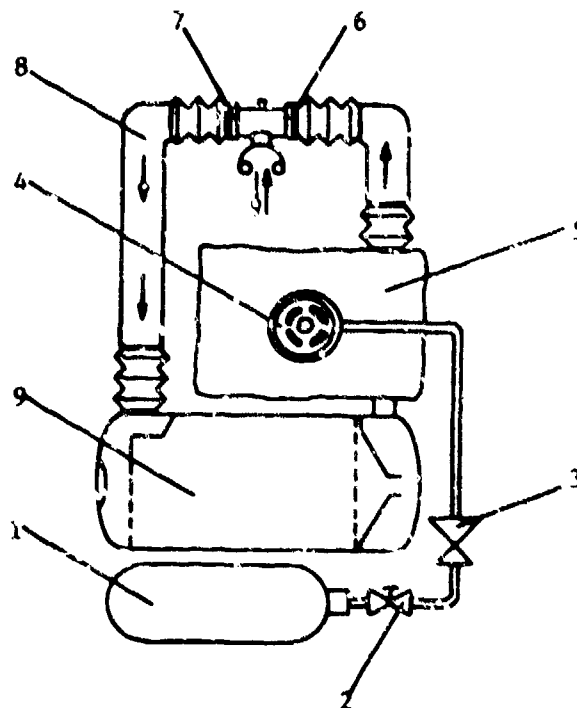


Figure 2. Functional Schematic

As the diver exhales, the exhalation check valve (7) opens, the inhalation check valve closes and the exhaled gas flows through the exhalation hose (8) to the CO<sub>2</sub> scrubber; it is then filtered through the CO<sub>2</sub> scrubber (9) with the next inhalation. During descent, or to purge the unit, the diver merely depresses the demand bypass valve in the front center of the case housing.

## TEST PROCEDURE

### TEST PLAN

Figure 3 illustrates test equipment setup. Unmanned LAR V testing met applicable military specifications. Appendix A provides the complete test plan. A breathing machine simulated inhalation and exhalation at various depths and diver work rates. Test equipment shown in figure 3 is listed in Appendix B.

### CONTROLLED PARAMETERS

A. The following parameters were controlled for breathing resistance tests.

1. Breathing rate/tidal volume
  - a. 15 BPM/1.5 liters      22.5 RMV
  - b. 20 BPM/2.0 liters      40.0 RMV
  - c. 25 BPM/2.5 liters      62.5 RMV
  - d. 30 BPM/2.5 liters      75.0 RMV
  - e. 30 BPM/3.0 liters      90.0 RMV
2. Exhalation/inhalation time ratio: 1.00/1.00
3. Breathing waveform: sinusoid
4. Breathing gas: nitrogen
5. Incremental descent stops: 0, 10, 25 and 40 FSW (breathing resistance tests only)

The CO<sub>2</sub> breakthrough test was conducted at both 70°F (21°C) and 39.2°F (4°C) at 25 FSW using H.P. Sodasorb.

B. Controlled parameters during canister duration tests were as follows:

1. CO<sub>2</sub> add rate:
  - a. 0.9 LPM at 23.0 RMV (2.0 LTV x 11.5 BPM)
  - b. 2.0 LPM at 50.0 RMV (2.0 LTV x 25 BPM)

NOTE: The CO<sub>2</sub> add rate and RMV are alternated at 4 and 6 minute intervals to simulate rest and moderate work rates (50 watts) performed on a bicycle ergometer by divers during manned equipment evaluations.

2. Relative humidity of exhaled gas: 95 percent
3. Exhaled gas temperature: 90°F (32°C) in 70°F (21°C) water  
86°F (30°C) in 39.2°F (4°C) water

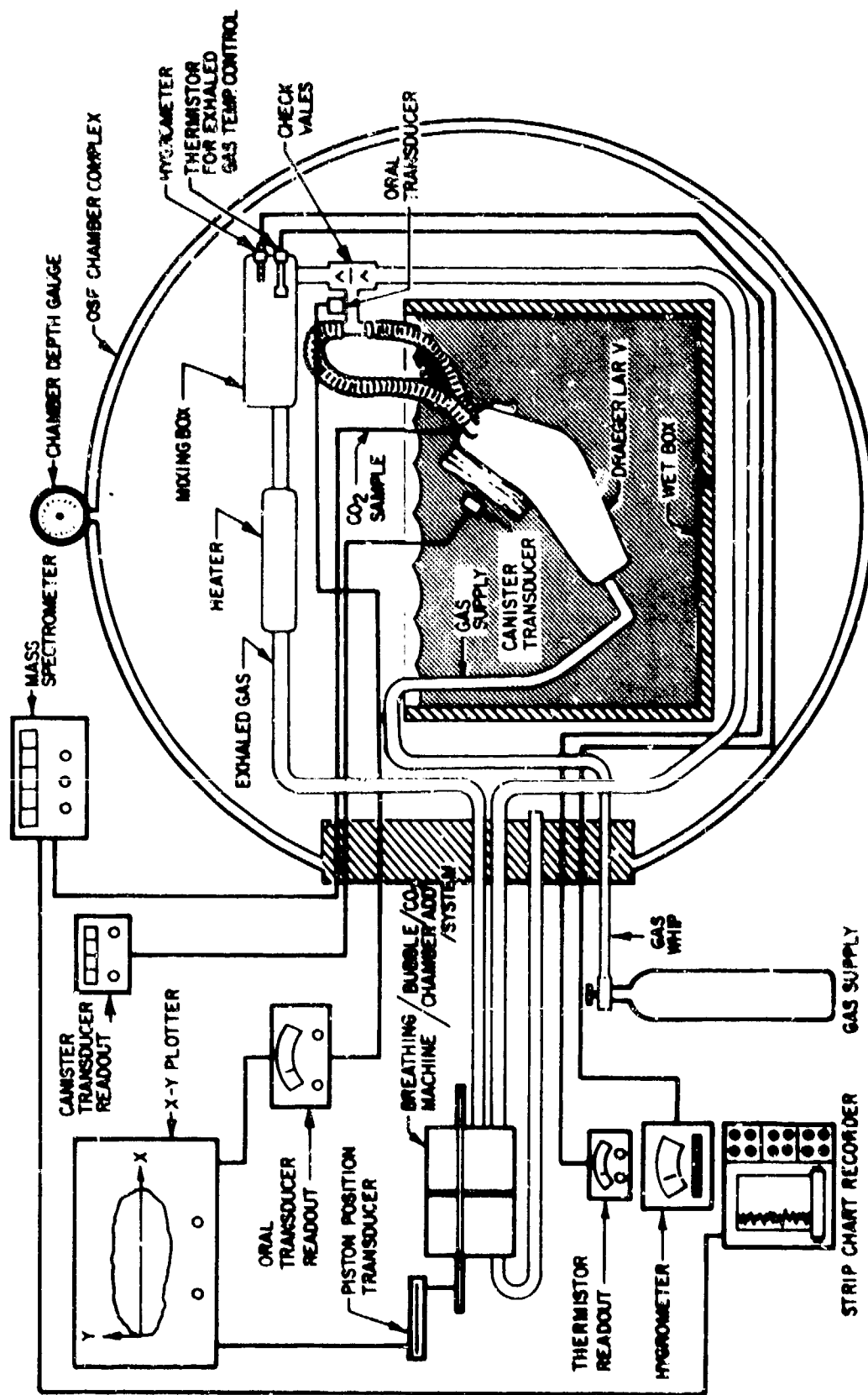


Figure 2. Test Setup

#### MEASURED PARAMETERS

1. Inhalation peak  $\Delta P$  (cm H<sub>2</sub>O)
2. Exhalation peak  $\Delta P$  (cm H<sub>2</sub>O)
3.  $\Delta P$  vs. tidal volume loop
4. Pressure drop across backpack (cm H<sub>2</sub>O)
5. CO<sub>2</sub> level out of scrubber in percent S.E. (canister duration tests only)
6. Exhaled gas relative humidity (canister duration tests only)
7. Exhaled gas temperature in °F (canister duration tests only)

#### COMPUTED PARAMETERS

Respiratory work (kg.m/l) is computed from  $\Delta P$  vs. tidal volume plots (breathing resistance tests only).

#### DATA PLOTTED

- A. The following data were for breathing resistance tests.
  1. Inhalation maximum  $\Delta P$  vs. depth
  2. Exhalation maximum  $\Delta P$  vs. depth
  3. Respiratory work vs. depth at constant RMV and supply pressure
  4. Maximum  $\Delta P$  across canister vs. time
- B. Canister duration test data plotted included:
  1. CO<sub>2</sub> out of scrubber vs. time
  2. Inhalation maximum  $\Delta P$  vs. time
  3. Exhalation maximum  $\Delta P$  vs. time



## RESULTS AND DISCUSSION

### BREATHING RESISTANCE TEST RESULTS

#### General

Breathing resistance was measured at five RMV's to simulate light through extreme diver work rates. Light work was measured at 22.5 RMV, moderate work at 40 RMV, moderately heavy work at 62.5 RMV, heavy work at 75 RMV and extreme work at 90 RMV. These tests were performed to indicate the full range of LAR V performance.

Breathing resistances plotted are maximum values measured during one complete inhalation/exhalation cycle at a given depth and RMV.

Figures 4 through 8 plot data from LAR V breathing resistance tests.

#### Inhalation Characteristics

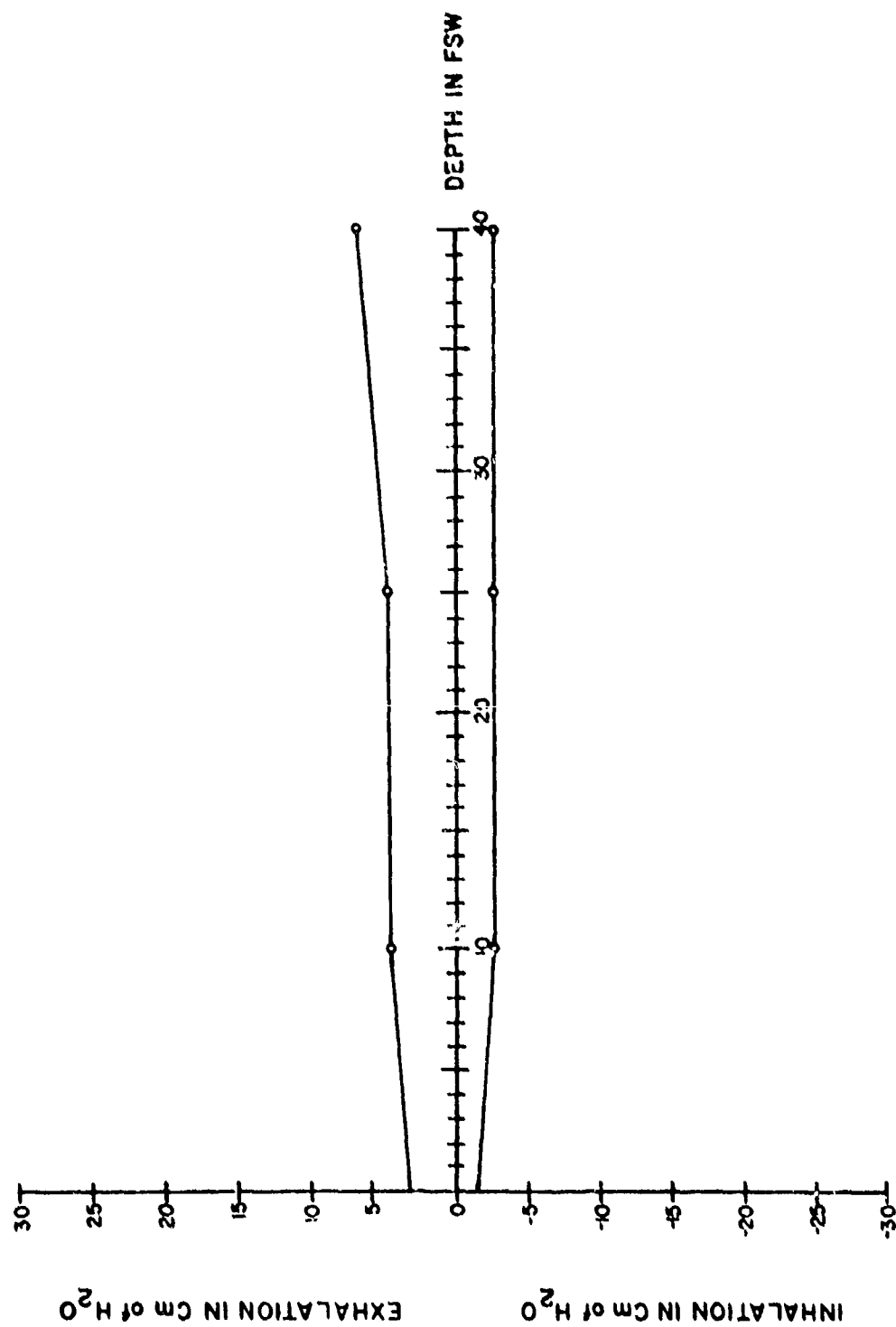
Inhalation resistance remained very low at 22.5 RMV (figure 4) regardless of depth and did not exceed 3.5 cm H<sub>2</sub>O. At 40 RMV (figure 5), resistance only reached 6 cm H<sub>2</sub>O at a depth of 40 FSW. The moderately heavy work rate of 62.5 RMV produced a slight increase at 25 FSW, reaching 11.5 cm H<sub>2</sub>O at 40 FSW (figure 6). Heavy work simulated with 75 RMV (figure 7) showed virtually no increase in inhalation resistance. At 90 RMV (figure 8) inhalation resistance peaked at 16.5 cm H<sub>2</sub>O at a depth of 40 FSW.

#### Exhalation Characteristics

Exhalation resistance remained relatively low at all depths at 22.5 and 40 RMV. At 62.5 RMV resistance increased gradually to 19 cm H<sub>2</sub>O at 40 FSW. Heavy work (75 RMV) produced 25.5 cm H<sub>2</sub>O of exhalation resistance at the LAR V depth limit. Maximum exhalation resistance of 29 cm H<sub>2</sub>O was encountered at 90 RMV at 40 FSW.

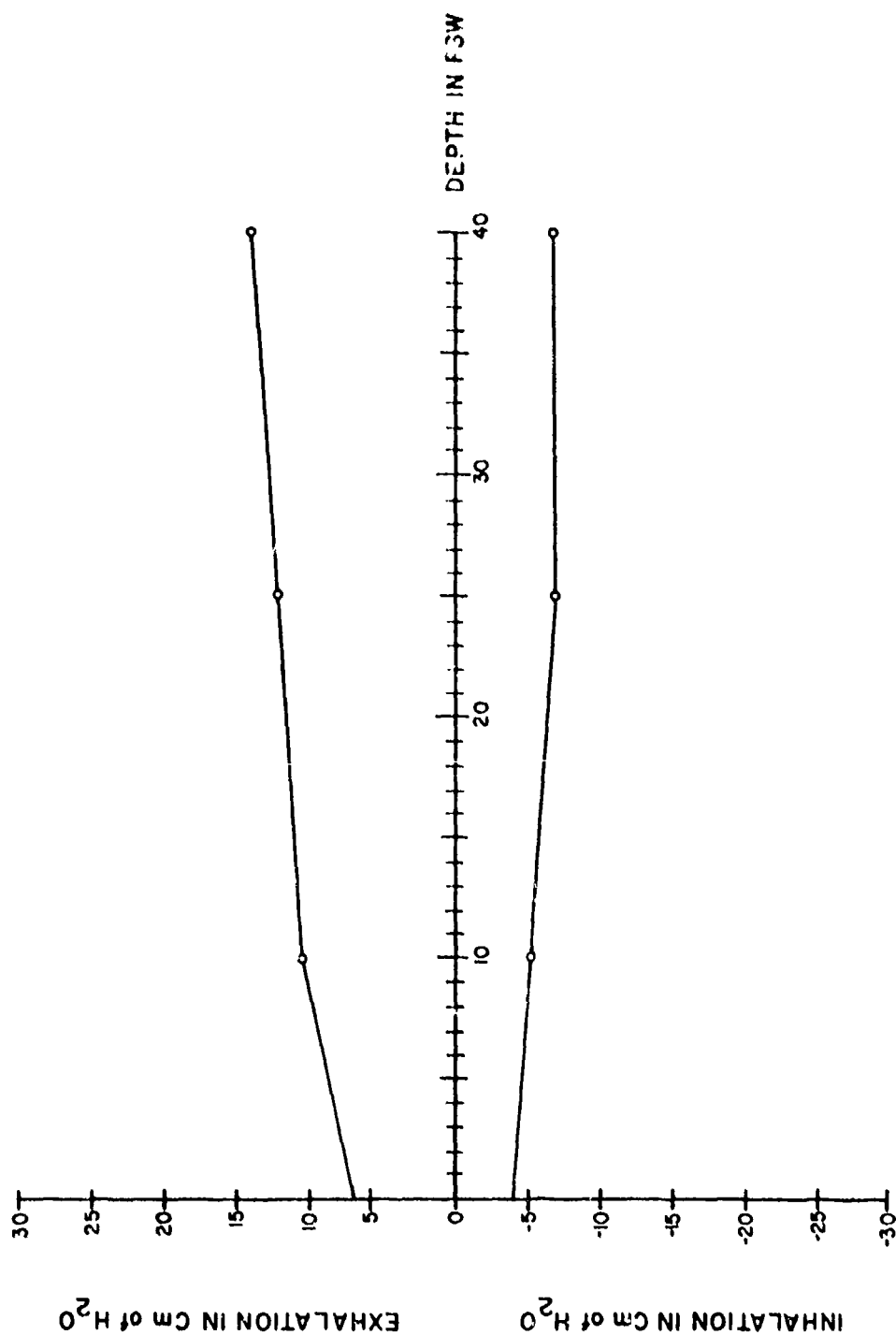
#### Breathing Work

The specifications governing testing of open circuit breathing apparatus cite peak inhalation and peak exhalation pressures as the standard for evaluation (reference 2). However, measurements of a diver's external respiration work in operating his breathing apparatus yield more useful data for evaluating closed circuit UBA performance (reference 3). (Breathing work is defined



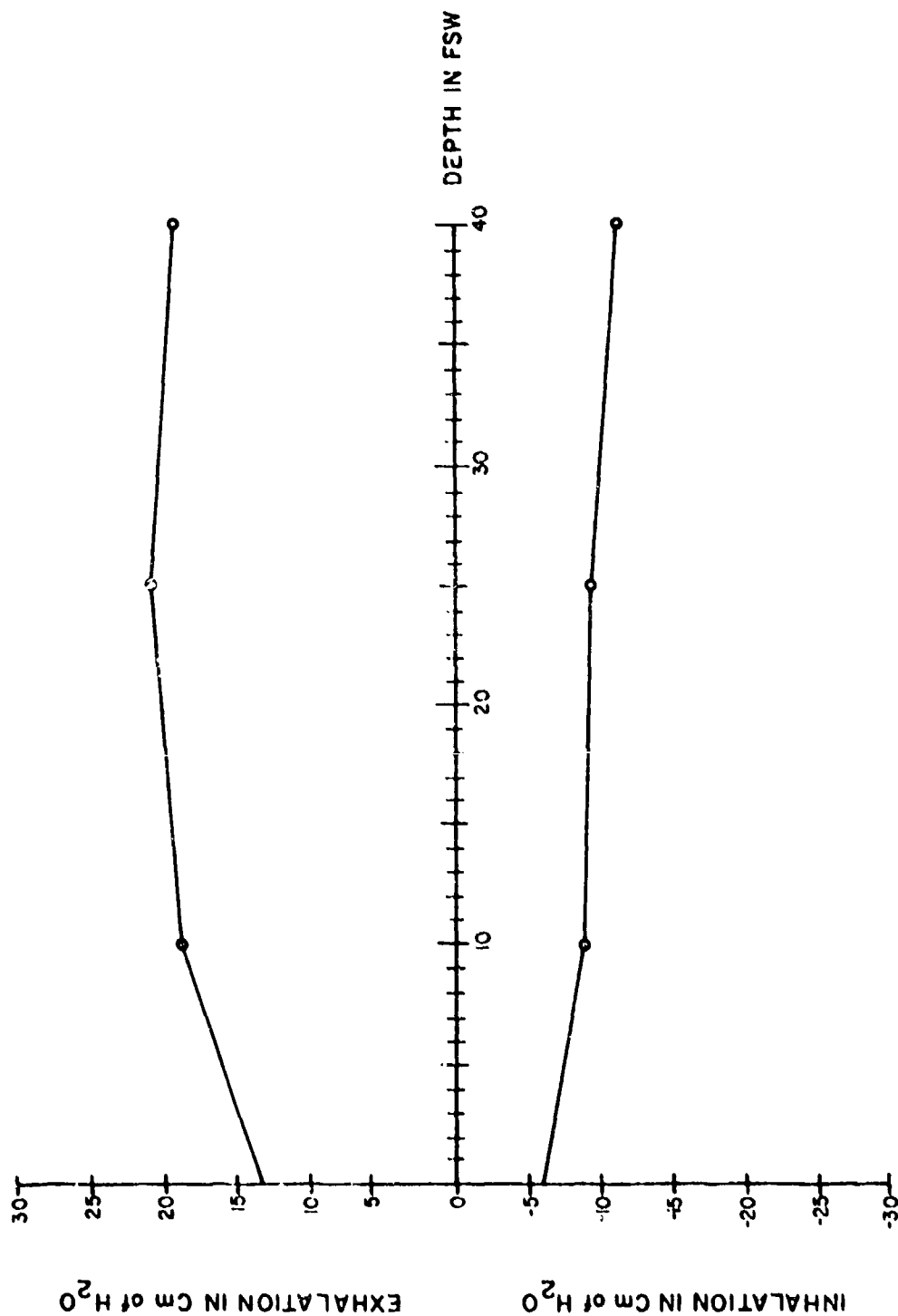
# BREATHING RESISTANCE VERSUS DEPTH

Figure 4. Draeger LAR V Test  
22.5 RMV



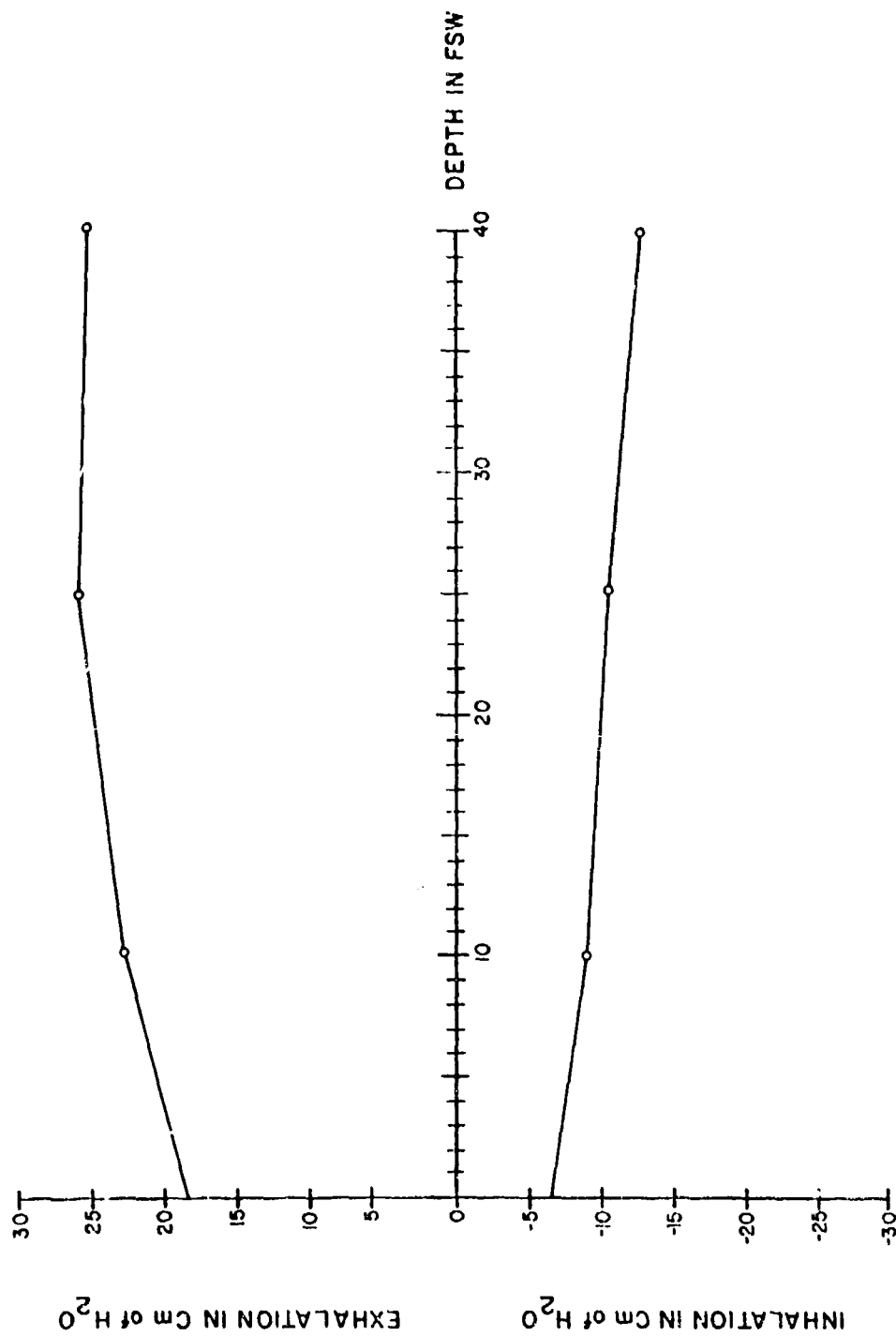
BREATHING RESISTANCE VERSUS DEPTH

Figure 5. Draeger LAR V Test  
40.0 RMV



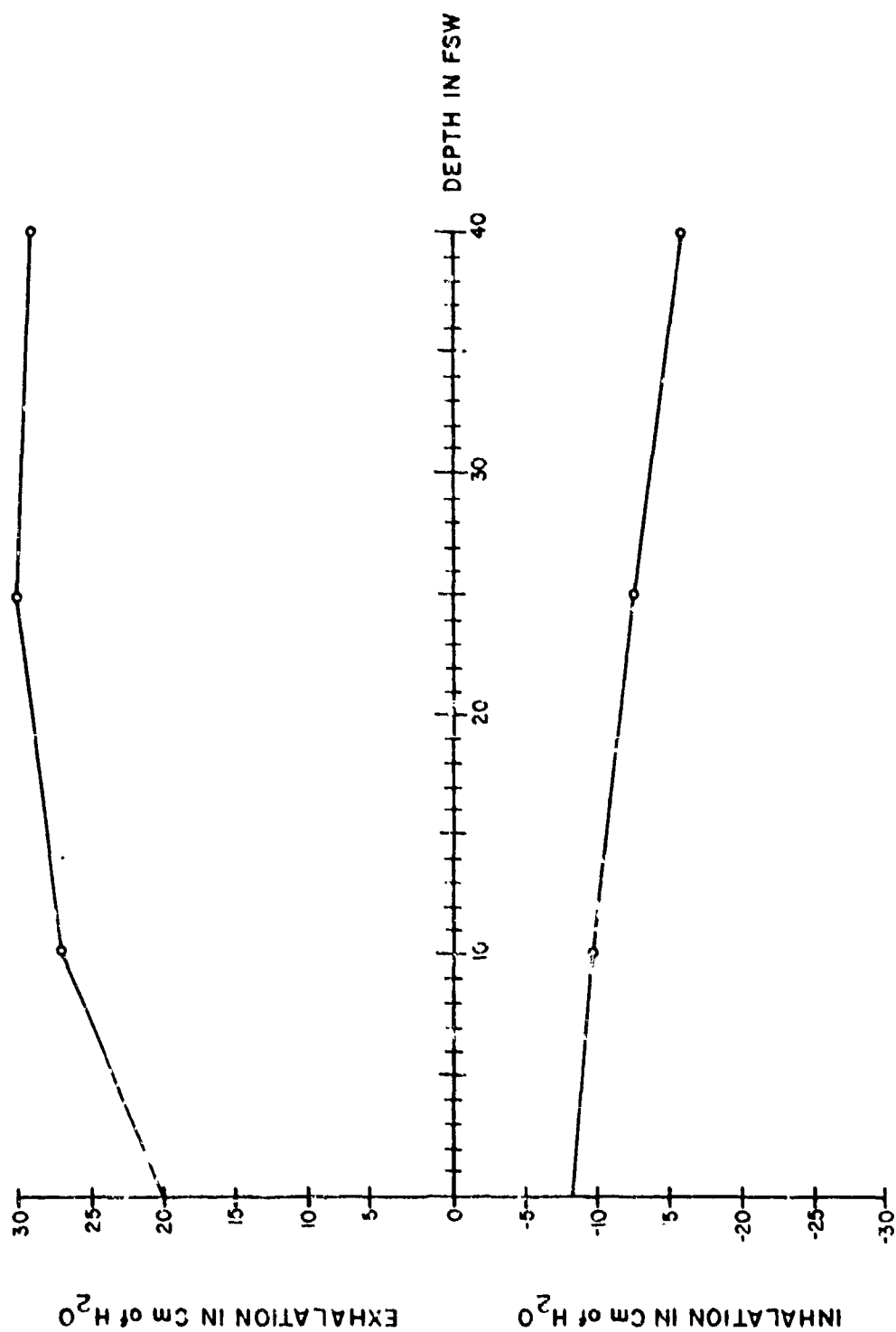
BREATHING RESISTANCE VERSUS DEPTH

Figure 6. Draeger LAR V Test  
62.5 RMV



BREATHING RESISTANCE VERSUS DEPTH

Figure 7. Draeger LAR V Test  
75.0 RMV



BREATHING RESISTANCE VERSUS DEPTH

Figure 8. Draeger LAR V Test  
90.0 RMV

as the area enclosed by a typical pressure-volume loop generated during one complete breathing cycle as illustrated in figure 9.)

Although the LAR V demand regulator permits adjustments to regulator cracking pressure from 10 to 30 cm H<sub>2</sub>O, the highest setting was maintained throughout the test. As a result, the breathing work plotted in figure 10 is an accurate reflection of light and moderate work (22.5 and 40 RMV) since the breathing bag was never fully deflated on inflation at these RMV's. Breathing work of the LAR V increases significantly at the higher RMV's; however, adjustment of the demand regulator to compensate for heavier work should cause a slight reduction in these values.

#### CANISTER DIFFERENTIAL PRESSURE

Canister differential pressures at the various RMV and incremental descent stops are plotted in figures 11 through 15. At 22.5 RMV and at a depth of 40 FSW, total exhalation resistance measured 6.0 cm H<sub>2</sub>O; canister AP at this RMV and depth constitutes 66 percent (4.0 cm H<sub>2</sub>O) of the exhalation resistance (figure 10). At 40.0 through 90.0 RMV, regardless of depth, the canister produced an average of 40 percent of the total exhalation resistance measured.

#### CO<sub>2</sub> CANISTER DURATION

The LAR V absorbent canister is a horizontally mounted, oval-shaped canister with a straight-through flow pattern. No baffles are present in the absorbent bed. Canister durations of 1 hour 15 minutes and 3 hours 47 minutes to 1.0% CO<sub>2</sub> S.E. value in 39°F (4°C) and 70°F (21°C) water, respectively, were within the range normally expected from an unheated canister holding 5.5 pounds of absorbent. Upon completion of each test, the canister bed was examined. Using the color indicating absorbent granules as a guide, complete and uniform bed usage was observed from the 70°F (21°C) water temperature test. The 39°F (4°C) water temperature test showed incomplete but uniform bed usage as would be expected under those conditions. Canister duration, plotted in 10-minute intervals for work and rest cycles, is shown in figure 16.

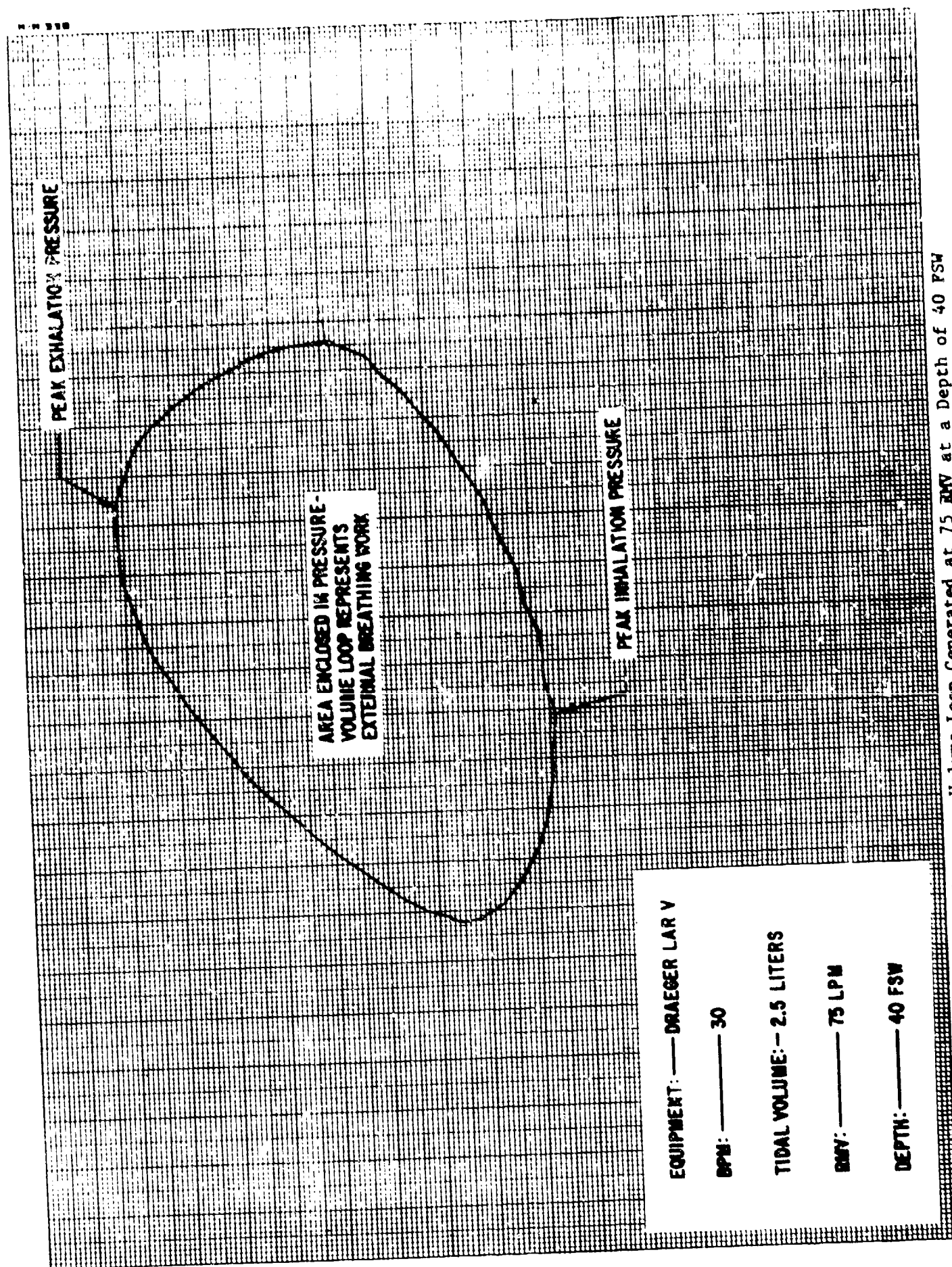
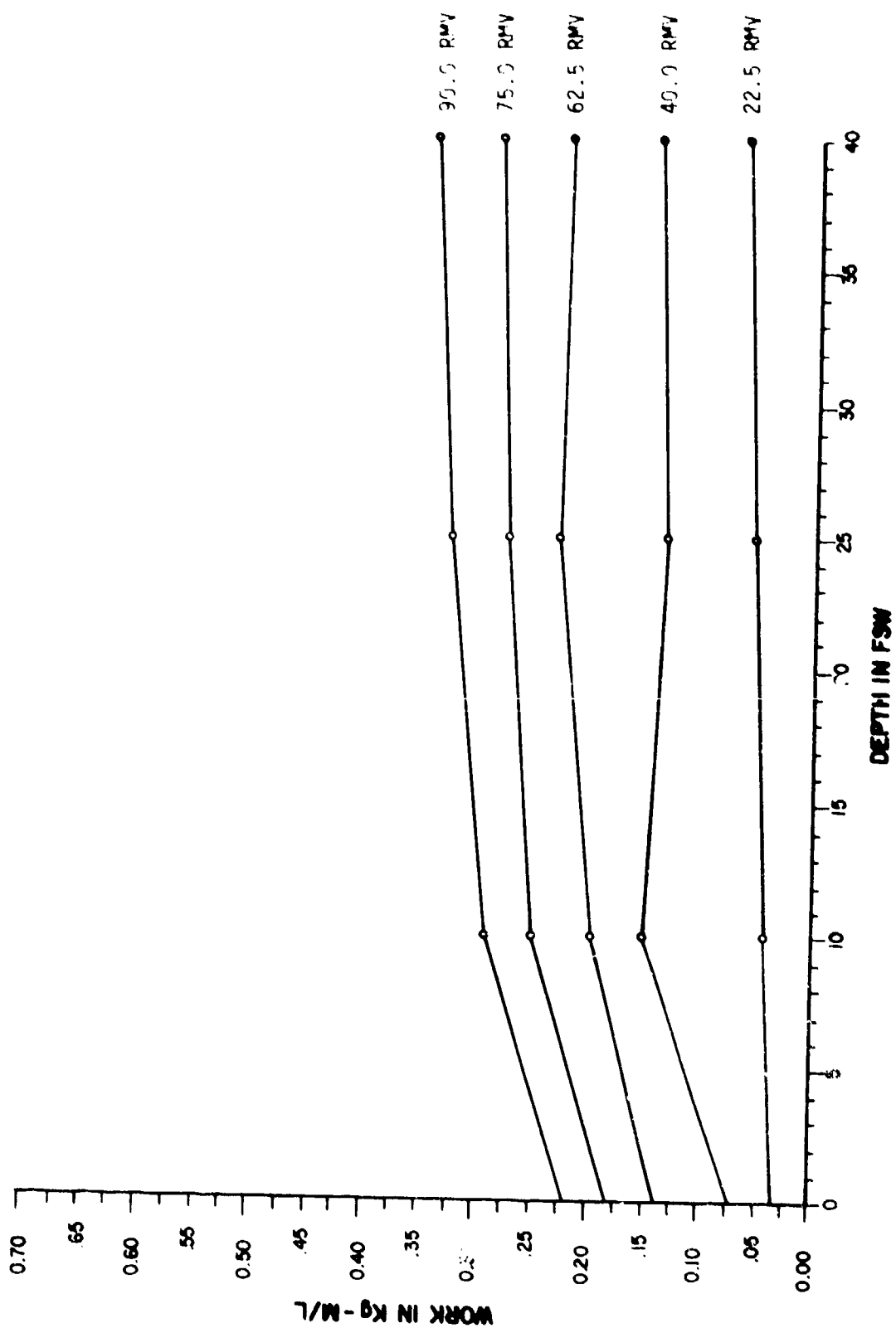


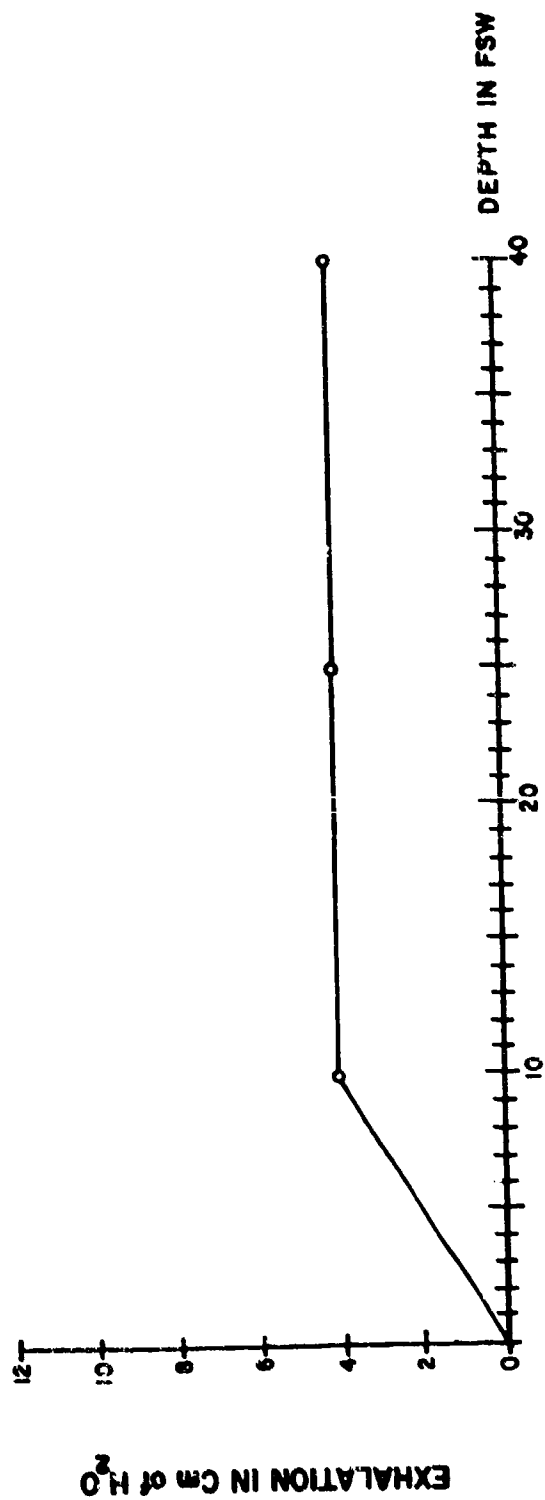
Figure 9. Pressure-Volume Loop Generated at 75 RMV at a Depth of 40 FSW





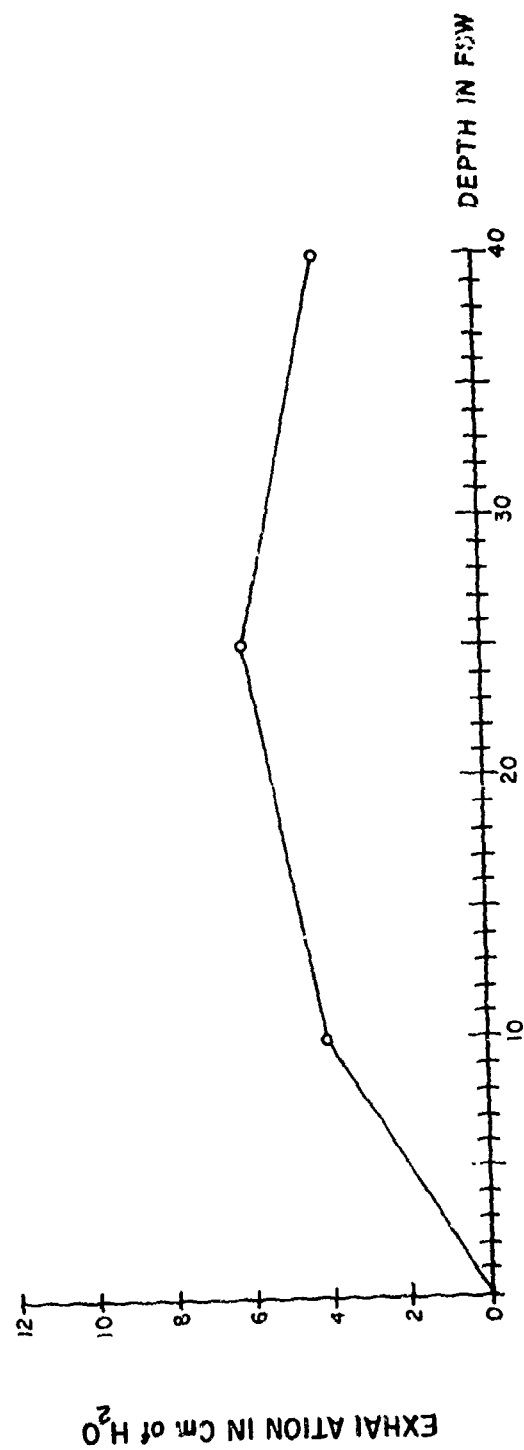
BREATHING WORK VERSUS DEPTH

Figure 10. Draeger LAR V Test



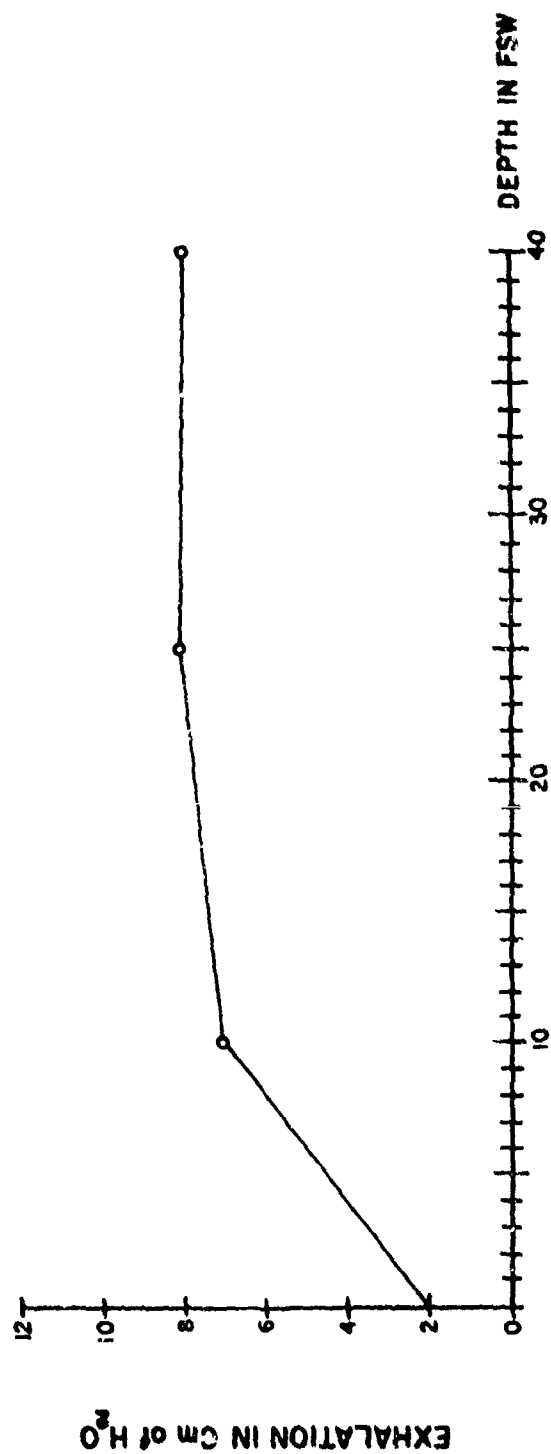
### CANISTER $\Delta P$ VERSUS DEPTH

Figure 11. Draeger LAR V Test  
22.5 RMV



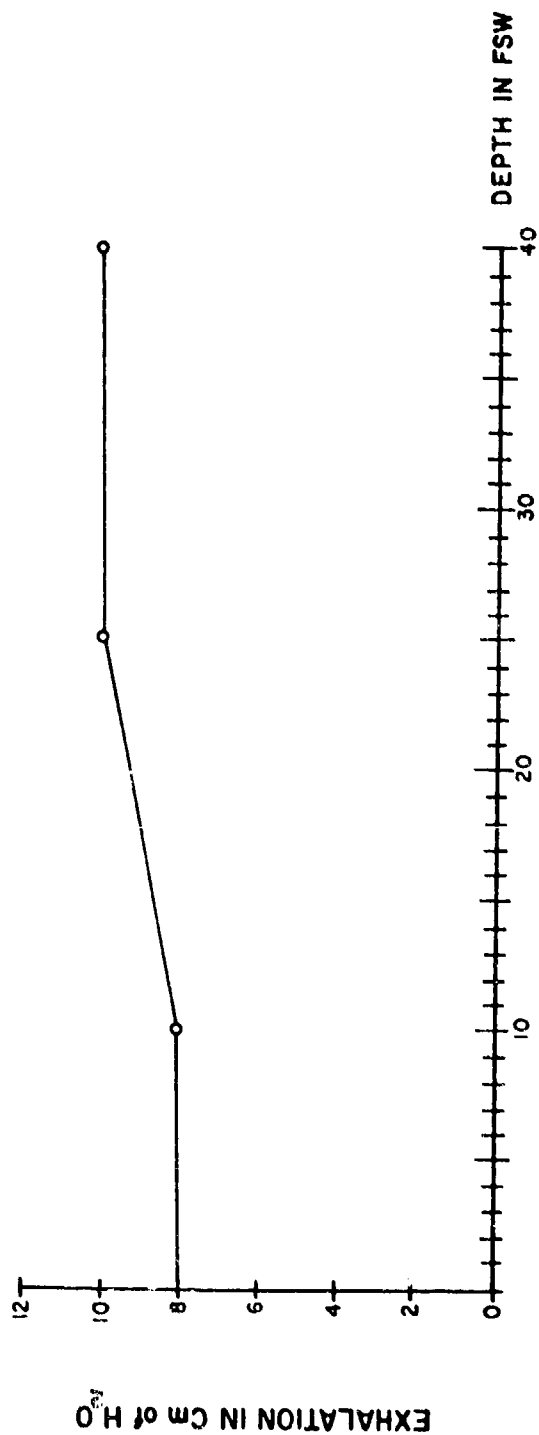
CANISTER  $\Delta P$  VERSUS DEPTH

Figure 12. Draeger LAR V Test  
40.0 RMV



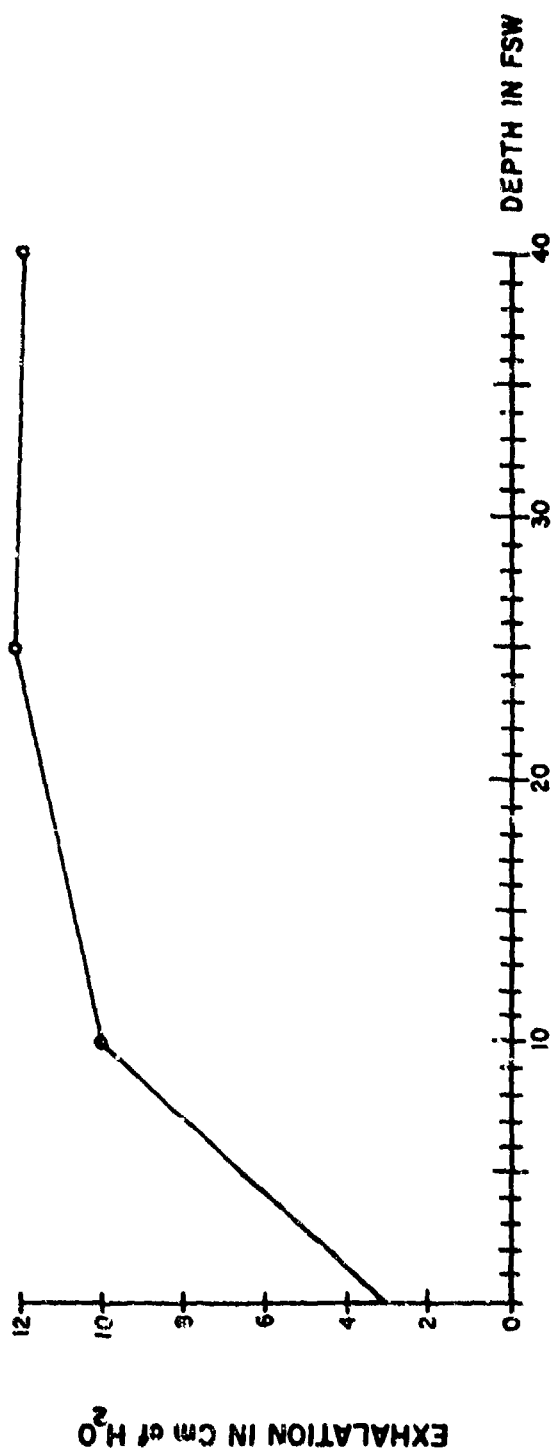
CANISTER  $\Delta P$  VERSUS DEPTH

Figure 13. Draeger LAR V Test  
62.5 BW



### CANISTER $\Delta P$ VERSUS DEPTH

Figure 14. Draeger LAR V Test.  
75.0 RMV



CANISTER  $\Delta P$  VERSUS DEPTH

Figure 15. Draeger LAR V Test  
90.0 RRV

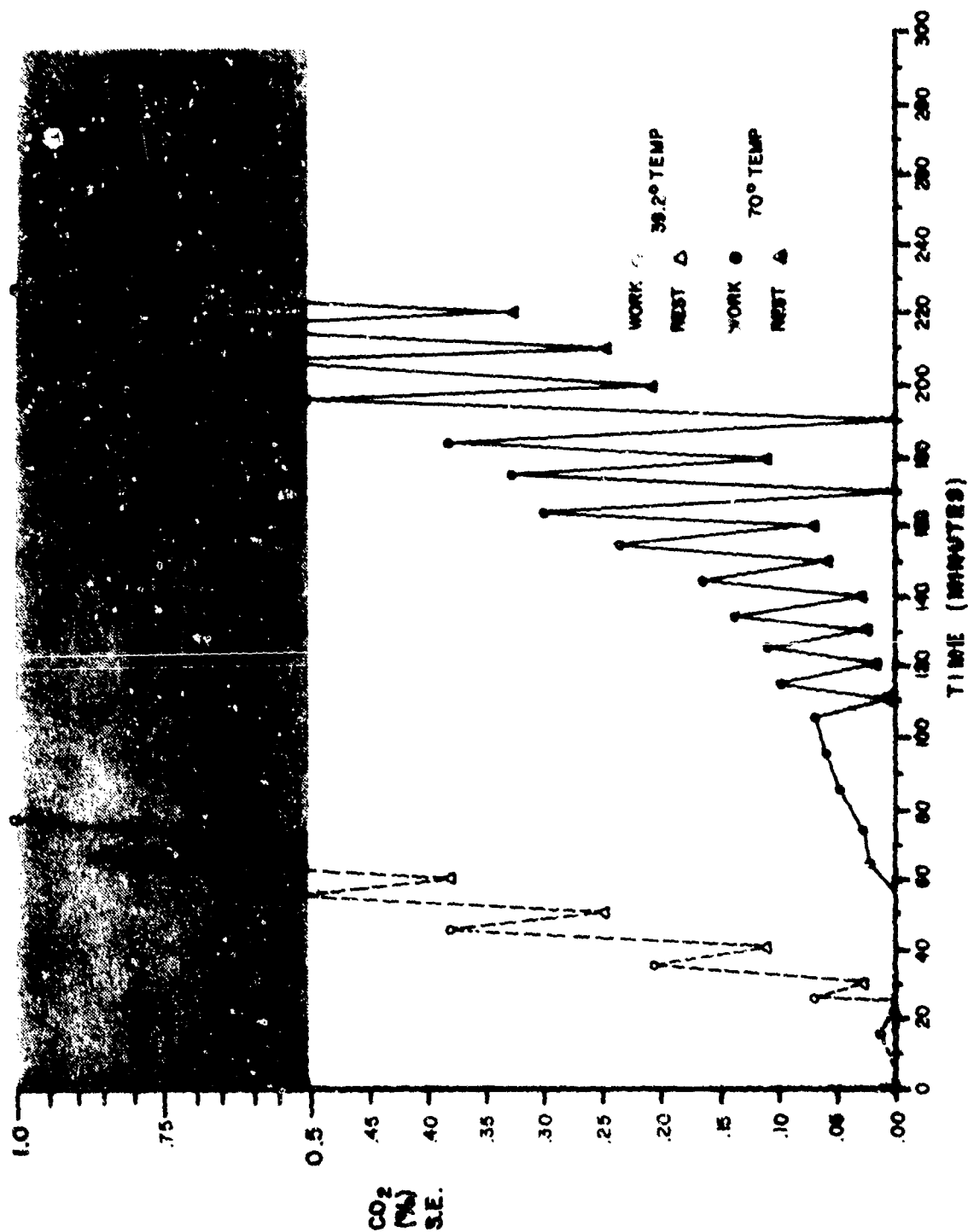


Figure 16. Draeger LAR V CO<sub>2</sub> Canister Breakthrough/Duration Test  
25 FSW

## CONCLUSIONS AND RECOMMENDATIONS

### BREATHING RESISTANCE

Peak inhalation and exhalation resistances were satisfactory at all depths and RMV's tested. However, exhalation pressures reached levels normally encountered only at much greater depths when tested at 75 and 90 RMV. Since maximum working depth for the rig is only 40 FSW this presents no real problem for the diver, but it is an indication that the breathing loop is marginally designed and can be improved significantly. No further testing is recommended in this area for ANU.

### RESPIRATORY WORK

Breathing work was not excessive at any depth or RMV tested. In fact, work levels remained almost constant at each RMV regardless of depth. Again, while breathing work was satisfactory, the levels reached at the higher RMV were greater than normally expected at such shallow operating depths and suggest that considerable improvements can be made in the design of the breathing loop.

### CANISTER PRESSURE DROP

The canister pressure drop produced 66 percent of the total exhalation resistance when light work was simulated at 40 FSW. At all other work rates (40.0 through 90.0 RMV) the amount of exhalation resistance attributable to the CO<sub>2</sub> scrubber canister averaged 40 percent regardless of depth. No modifications to the canister are recommended for ANU.

### CO<sub>2</sub> SCRUBBER BREAKTHROUGH/DURATION TEST

In warm water (70°F [21°C]) at a depth of 25 FSW the scrubber of the LAR V reached a 0.5% CO<sub>2</sub> surface equivalent after 3 hours 16 minutes and 1.0% CO<sub>2</sub> S.E. after 3 hours 47 minutes. In cold water (39°F [4°C]) 0.5% CO<sub>2</sub> S.E. occurred after 48 minutes; canister breakthrough at 1.0% CO<sub>2</sub> S.E. took place after 1 hour 15 minutes.

Since the LAR V will be normally operating in water less than 70°F (21°C), it is recommended that manned canister duration tests be conducted in cold water to further verify the short canister durations measured during unmanned tests.



#### REFERENCES (PART I)

1. Navy Experimental Diving Unit Report 11-75, Evaluation of the Draeger LAR V Pure Oxygen Scuba by Paulsen and Jarvi, 8 October 1975.
2. Department of the Navy Military Specification MIL-R-24169A, Regulator, Air, Demand, Single Hose, Nonmagnetic, Divers, 22 March 1967.
3. Navy Experimental Diving Unit Report 19-73, Proposed Standards for the Evaluation of the Breathing Resistance of Underwater Breathing Apparatus, by S.D. Reimers, 30 January 1974.

## APPENDIX A

### 1. Test plan for breathing resistance tests.

- a. (1) Insure that LAR V is set to factory specifications and is working properly.
  - (2) Chamber is on surface.
  - (3) Calibrate transducers.
  - (4) Open O<sub>2</sub> supply valve to test UBA.
  - (5) Adjust breathing machine to 1.5 liter tidal volume and 15 BPM and take readings.
  - (6) Adjust breathing machine to 2.0 liter tidal volume and 20 BPM and take readings.
  - (7) Adjust breathing machine to 2.5 liter tidal volume and 25 BPM and take readings.
  - (8) Adjust breathing machine to 2.5 liter tidal volume and 30 BPM and take readings.
  - (9) Adjust breathing machine to 3.0 liter tidal volume and 30 BPM and take readings.
  - (10) Stop breathing machine.
- b. (1) Pressurize chamber to 10 FSW.
  - (2) Repeat steps 1.a(5) through 1.a(10).
- c. (1) Pressurize chamber to 25 FSW.
  - (2) Repeat steps 1.a(5) through 1.a(10).
- d. (1) Pressurize chamber to 40 FSW.
  - (2) Repeat steps 1.a(5) through 1.a(10).
- e. (1) Bring chamber to surface.
  - (2) Check calibration on transducers.

### 2. Test plan for CO<sub>2</sub> canister duration tests.

- a. (1) Insure that LAR V is set to factory specifications and is working properly using Baralyne.
  - (2) Chamber is on surface.
  - (3) Calibrate transducers and mass spectrometer.
  - (4) Open O<sub>2</sub> supply valve to test UBA.

- (5) Water temperature to be approximately 70°F (21°C).
- (6) Start humidity add system.
- (7) Compress chamber to 25 FSW at 75 FPM.
- (8) Start CO<sub>2</sub> add and maintain following procedure until

1.0% S.E. CO<sub>2</sub> is reached:

- (a) 4 minutes at 0.9 LPM CO<sub>2</sub> add/2.0 liter tidal volume and 11.5 BPM
- (b) 6 minutes at 2.0 LPM CO<sub>2</sub> add/2.0 liter tidal volume and 25 BPM

- (9) Take data every 15 minutes to breakthrough
- b. Repeat step 2.a at water temperature of 40°F (4°C).

## APPENDIX B

### Test equipment used:

- (1) Breathing machine/CO<sub>2</sub> add system/Bubble chamber (Relative humidity and exhaled gas control system)
- (2) Validyne pressure transducer w/1.00 psid diaphragm (oral pressure and canister  $\Delta P$ ) (2 ea)
- (3) Validyne CD-19 transducer readout (2 ea)
- (4) Ice for wet test box during cold water canister duration tests
- (5) X-Y plotter
- (6) Wet test box
- (7) Mass spectrometer for analysing CO<sub>2</sub> out of scrubber
- (8) NEDU OSF chamber complex
- (9) External nitrogen supply for Draeger LAR V UBA
- (10) Mixing box for sampling CO<sub>2</sub>
- (11) Chamber depth gauge
- (12) Test UBA: Modified Draeger LAR V
- (13) Breathing machine piston position transducer
- (14) Relative humidity sensor and readout
- (15) Strip chart recorder
- (16) Exhaled Gas Resistance Heaters

## PART II: MANNED TESTING

### INTRODUCTION

At the completion of unmanned testing of the modified Draeger LAR V closed-circuit oxygen rebreather by NEDU, 48 minute canister durations in cold water precluded ANU status without further investigation. The role of CO<sub>2</sub> in the exacerbation of central nervous system oxygen toxicity is well known (4), and any closed-circuit oxygen rebreather should efficiently remove CO<sub>2</sub> for periods of time at least equal to the oxygen diving limits in the U.S. Navy Diving Manual (table 13-1 and figure 13-2, 1973).

A series of twenty-four manned oxygen dives were therefore undertaken in 70°F (21°C) and 40°F (4°C) water to determine the life expectancy of LAR V carbon dioxide absorbent canisters and to evaluate other aspects of rig performance under conditions of sustained, heavy work at 25 FSW.

Modifications to the standard Draeger LAR V for manned testing were the same as for unmanned testing, consisting only of reversal of the breathing loop to correspond to the counterclockwise gas flow of standard U.S. Navy equipment. A detailed equipment description of the modified LAR V and a discussion of the functional aspects of this closed-circuit oxygen rebreather system can be found in Part I of this report.

### TEST PROCEDURE

Six U.S. Navy UDT/SEAL divers, ages 23-30, served as subjects. Each subject had passed a standard USN oxygen tolerance test prior to beginning diving training, and was experienced in the use of closed-circuit oxygen rebreathing apparatus. The divers were well conditioned, and prior to the experimental series were capable of running eight km per day and pedalling 200 watts for 10 minutes on a pedal ergometer. Standard oxygen consumption and carbon dioxide production data were obtained from each diver in the dry laboratory on air at 1 ata prior to the dives.

All oxygen exposures were performed in the wet pot of the OSF compressed to a simulated depth of 22 FSW. The divers exercised on a specially modified,

electrically braked pedal ergometer (5) mounted on a horizontal frame placed three feet underwater. The depth at the diver's thorax was 25 FSW for all studies. Each diver wore a LAR V closed-circuit oxygen rebreather (Draegerwerk AG) containing approximately 4.3 kg of H.P. Sodasorb (W. R. Grace Co.) as the CO<sub>2</sub> absorbent. The diving apparatus was carefully purged at the start of the experiment to obtain an oxygen concentration in excess of 95 percent. Continuous oxygen and inert gas sampling from the rig during the experiment quickly increased oxygen concentrations to 99 percent.

The experiment was divided into two parts; the first part consisted of CO<sub>2</sub> absorbent canister duration studies, and the second part was graded exercise studies. During the canister duration studies, subjects pedalled the ergometer at 50 watts for six minutes and rested for four minutes. This sequence continued until inspired P<sub>CO<sub>2</sub></sub> reached 7.6 mmHg (1.0% S.E.), or for a maximum of five hours. Graded exercise consisted of eight 10-minute cycles beginning with one cycle of 10 minutes of rest, followed by seven cycles of six minutes of work and four minutes of rest. The work rates were 25, 50, 75, 75, 100, 125 and 150 watts respectively. All measurements were taken during the final three minutes of each exercise period. Both graded exercise and canister duration studies were performed in 70°F (21°C) water with each diver wearing a full 1/4-inch neoprene wet suit, and then repeated in 40°F (4°C) water with each diver wearing a variable volume dry suit (Bailey suit). Divers were briefed regarding signs and symptoms of oxygen toxicity, and all subjects were accompanied by an air breathing standby diver at all times.

Gas samples from the canister outlet and mouthpiece were continuously monitored for P<sub>O<sub>2</sub></sub> and P<sub>CO<sub>2</sub></sub> with a Mass Spectrometer (Chemetron Medspect 2). A small diameter gas sample line minimized gas sample mixing and allowed good frequency response, thereby permitting interpretation of end tidal P<sub>CO<sub>2</sub></sub> values (6). In addition, heart rate and rectal temperature were monitored, and differential pressures between the mouth and ambient hydrostatic pressure at mouth level were measured with a 5 psi variable reluctance pressure transducer (Validyne DP-9). All parameters were recorded on an eight-channel strip chart recorder. Mean oxygen consumption (VO<sub>2</sub>) was computed from oxygen

supply bottle pressure drop measured with a 3000 psi variable reluctance pressure transducer (Validyne, DP-15), the known volume of the supply bottle, and suitable corrections for gas sample rate and temperature.

## RESULTS AND DISCUSSION

Table 1 summarizes the results of the warm and cold water canister duration studies. Canister breakthrough was defined as the number of minutes required for canister effluent  $\text{CO}_2$  to reach 3.8 mmHg (0.5% S.E.). In 70°F (21°C) water, mean canister breakthrough was  $226 \pm 23$  minutes. Diver No. 1 had a shorter oxygen exposure because his oxygen supply bottle was partially depleted during the initial purge procedures. Diver No. 5 had his test terminated at 178 minutes and an inspired  $\text{P}_{\text{CO}_2}$  of 3.0 mmHg (0.4% S.E.) because of five seconds of ringing in his right ear. This resolved before he came off oxygen, and his own impression was that the ringing was "normal" for him but that he should report it. This was the only symptom consistent with potential CNS oxygen toxicity noted during the entire study.

Mean canister breakthrough during the 40°F (4°C) canister duration studies was  $124 \pm 9$  minutes. Wet pot temperature during Diver No. 2's cold water dive was only 50°F (10°C) and his canister duration was longer than the other five cold water canister duration studies. All divers were subjectively cold during these exposures, and particularly complained of cold extremities. Mean rectal temperature decreased  $1.0 \pm 0.2^\circ\text{C}$  during these six exposures following an initial rise of about  $0.2^\circ\text{C}$  during the first few minutes after immersion in the cold water. In spite of falling rectal temperature and intermittent shivering, mean oxygen consumption, and therefore mean carbon dioxide production during the cold water canister duration studies was not significantly higher than during the warm canister duration studies (table 1). Mean oxygen consumption for all six cold water duration dives was  $1.37 \pm 0.18$  SLPM, which indicates that the amount of  $\text{CO}_2$  presented to the canister during manned studies was less than the 1.56 SLPM mean  $\text{CO}_2$  injection rate used during unmanned testing. This may account for part of the large difference between manned and unmanned cold water canister durations.

Table 1. Summary of Canister Duration Studies at 25 PSW

Diver No.	Water Temperature 70°F (21°C)			Water Temperature 40°F (4°C)		
	Canister Duration (Min to 0.5% CO <sub>2</sub> S.E.)	VO <sub>2</sub> (SLPM) at 50 Watts	VO <sub>2</sub> (SLPM) Mean <sup>1</sup>	Canister Duration (Min to 0.5% CO <sub>2</sub> S.E.)	VO <sub>2</sub> (SLPM) at 50 Watts	VO <sub>2</sub> (SLPM) Mean <sup>1</sup>
1	220	1.62	1.25	128	1.59	1.13
2	230	1.74	1.29	180 <sup>2</sup>	1.93	1.38
3	235	1.69	1.20	135	1.76	1.62
4	218	1.58	1.15	125	1.92	1.42
5	190	----	1.35	115	----	----
6	260	1.77	1.29	115	1.97	1.32
Mean ± sd	226 ± 23	1.72 ± 0.11	1.28 ± 0.09	124 ± 9	1.83 ± 0.16	1.37 ± 0.18

<sup>1</sup>Mean VO<sub>2</sub> is the total standard volume of O<sub>2</sub> consumed divided by the length of the exposure.

<sup>2</sup>Wet pot water temperature was 50°F (10°C) for this dive, and it is not included in the mean canister duration for 40°F (4°C).



Figure 17 graphs inspired  $P_{CO_2}$  versus time for all subjects in warm and cold canister duration studies. The shape of these curves is typical for  $CO_2$  absorbent canister breakthrough in closed or semi-closed UBA, and the diminished life expectancy in cold water is characteristic (7).

Table 2 summarizes the results of the twelve graded exercise studies. Mean oxygen exposure time was  $85 \pm 4$  minutes. The mass of  $CO_2$  delivered in the absorbent canister during the 80-minute graded exercise was approximately the same amount delivered to the canister during the first 120 minutes of a canister duration, and accounts for the increased inspired  $P_{CO_2}$  during the final work loads of the cold water graded exercise studies. The higher oxygen consumptions at the lower work loads in the cold graded exercises probably reflect shivering, and also contribute to the  $CO_2$  load delivered to the canister.  $CO_2$  "Blow-by" was not seen during graded exercise.

Figure 18 graphs end tidal  $P_{CO_2}$  versus work rate for all graded exercise studies. End tidal  $P_{CO_2}$  levels in the cold studies increased at high work loads in proportion to the increase in inspired  $P_{CO_2}$ . Breathing resistance did not exceed  $22 \pm 4$  cm of water at high work rates and this was sufficiently low to prevent an increase in end tidal  $P_{CO_2}$  with heavy work (table 2).

#### CONCLUSIONS AND RECOMMENDATIONS

The functional performance of the modified Draeger LAR V during 24 oxygen dives at 25 FSW was satisfactory in both warm and cold water experiments, and as such the LAR V can be recommended for ANU status. The canister duration studies showed significant inter-subject variability (table 1), and for this reason, one standard deviation was subtracted from actual mean canister duration to obtain proposed operational limits for the use of the modified LAR V. These limits are graphed in figure 19. A linear fit was employed because it provided the widest safety margin.

The maximum operational limit for the LAR V in 70°F or warmer water is 200 minutes. Interpolation from figure 19 for water temperatures between 40°F (4°C) and 70°F (21°C) is permitted as shown. However, extrapolation of figure 19 for water temperatures below 40°F (4°C) is not recommended since no test data is available.

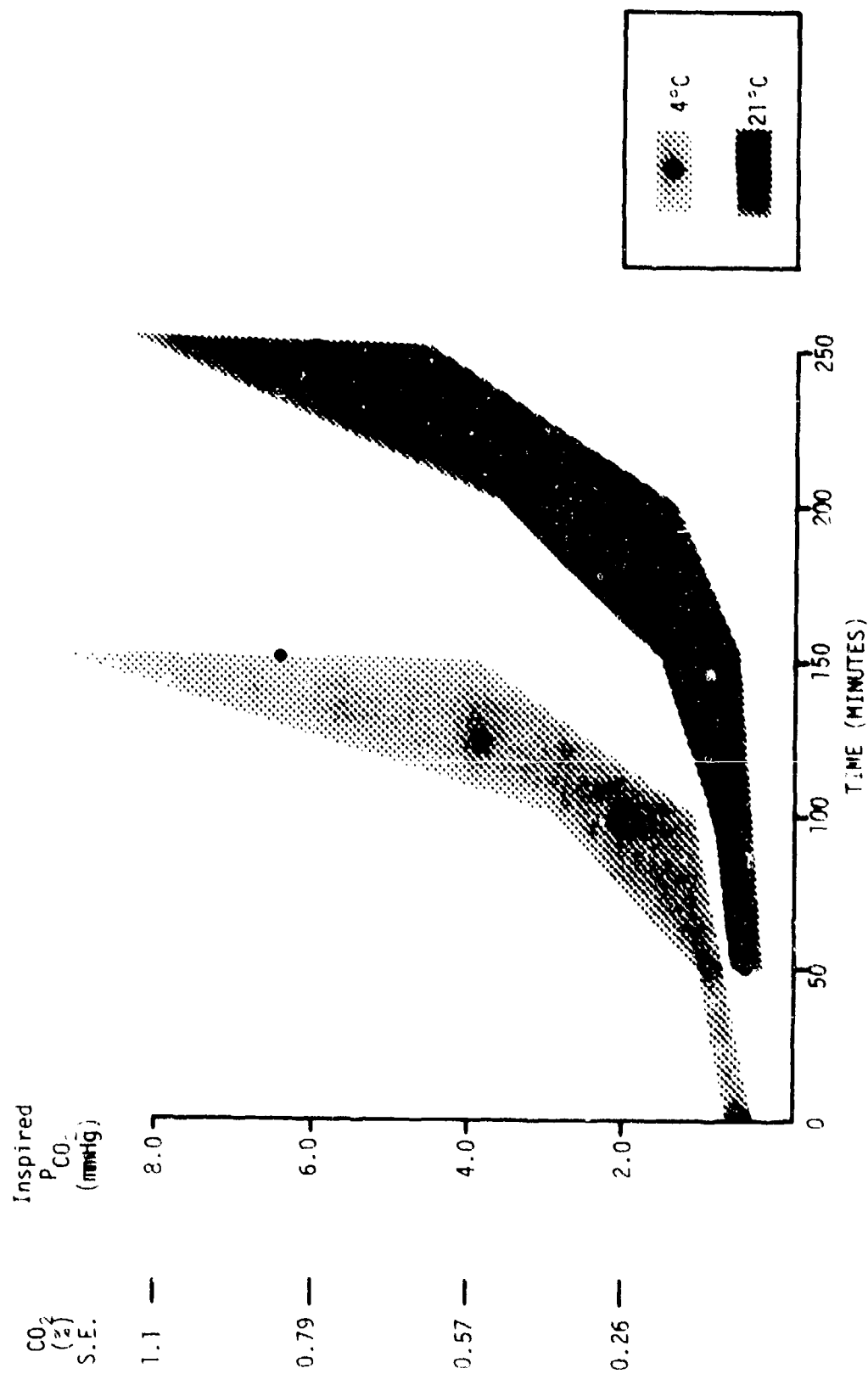


Figure 17. Inspired  $P_{CO_2}$  Versus Time for All Subjects During Warm (21°C [70°F]) and Cold (4°C [39°F]) Canister Duration Studies. Shaded Areas Represent  $\pm$  One Standard Deviation from the Mean.

Table 2. Summary of Graded Exercise Studies at 25 FSW

WATER TEMPERATURE 21°C										WATER TEMPERATURE 4°C						
Diver		Rest	25	50	75	100	125	150		Rest	25	50	75	100	125	150
V <sub>O</sub> Z (SLPM)	1	-	1.53	1.81	2.04	2.26	2.47	2.97		-	1.79	2.11	2.11	2.27	2.27	2.61
	2	-	-	1.39	1.69	1.84	2.32	2.95		-	2.25	1.91	1.79	2.19	2.37	2.95
	3	-	1.53	1.69	1.92	2.13	2.26	-		-	-	-	-	-	-	-
	4	-	1.38	1.53	1.24	2.33	2.67	2.84		-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-		-	1.95	1.90	1.98	2.46	3.00	3.71
	6	-	1.61	1.94	2.28	2.55	2.89	3.23		-	1.46	2.62	1.80	2.12	3.19	3.17
Mean ± SD		-	1.51 ± 0.10	1.67 ± 0.22	1.95 ± 0.22	2.22 ± 0.26	2.52 ± 0.26	3.03 ± 0.17		-	2.00 ± 0.33	2.12 ± 0.32	2.00 ± 0.22	2.23 ± 0.14	2.65 ± 0.42	3.16 ± 0.42
Peak End Tidal CO <sub>2</sub> (mmHg)	1	34	42	45	45	46	47	48		34	33	45	45	46	47	48
	2	35	45	45	46	45	42	42		31	42	42	42	46	48	54
	3	34	45	47	46	47	47	47		34	42	46	46	47	47	48
	4	31	39	42	42	42	42	42		-	-	-	-	-	-	-
	5	30	39	45	46	45	46	46		34	46	46	47	48	48	48
	6	33	45	46	45	45	47	47		31	42	42	47	47	47	51
Mean ± SD		33 ± 2	43 ± 3	45 ± 2	45 ± 2	45 ± 2	45 ± 2	45 ± 3		33 ± 2	41 ± 5	44 ± 2	46 ± 1	47 ± 1	47 ± 1	50 ± 3
Inspired CO <sub>2</sub> (mmHg)	1	0.7	0.8	0.8	0.8	1.0	1.0	1.0		0.8	0.8	0.8	1.1	1.5	2.0	2.4
	2	0.4	0.4	0.5	0.5	0.5	0.5	0.5		0.4	0.4	0.4	0.6	0.7	1.0	1.8
	3	0.4	0.4	0.4	0.4	0.7	1.2	1.2		0.4	0.8	0.8	1.0	1.2	1.6	2.5
	4	0.4	0.4	0.4	0.4	0.5	0.6	0.6		0.7	-	0.7	1.0	1.6	2.3	4.5
	5	0.4	0.4	0.4	0.4	0.7	1.0	1.5		0.7	0.8	0.8	1.1	1.6	2.5	4.5
	6	0.4	0.4	0.4	0.6	0.6	0.6	0.6		0.7	1.0	1.0	1.0	1.4	2.1	3.1
Mean ± SD		0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.9 ± 0.4		0.6 ± 0.2	0.8 ± 0.2	0.8 ± 0.2	1.0 ± 0.2	1.3 ± 0.3	1.9 ± 0.5	3.1 ± 1.1
Mouth Differential Pressure (cm H <sub>2</sub> O)	1	12	14	16	19	20	24	26		10	12	14	16	18	22	26
	2	10	14	16	18	20	20	20		8	14	16	18	18	18	18
	3	10	12	14	14	16	18	22		8	12	12	14	16	18	20
	4	8	10	14	16	18	22	24		12	-	18	24	24	26	28
	5	8	10	12	12	12	14	18		12	10	12	14	16	18	22
	6	10	12	14	16	18	18	18		8	12	14	14	16	18	18
Mean ± SD		10 ± 2	12 ± 2	14 ± 2	21 ± 3	19 ± 2	20 ± 3	21 ± 3		9 ± 2	12 ± 1	14 ± 2	17 ± 4	18 ± 3	20 ± 4	22 ± 4

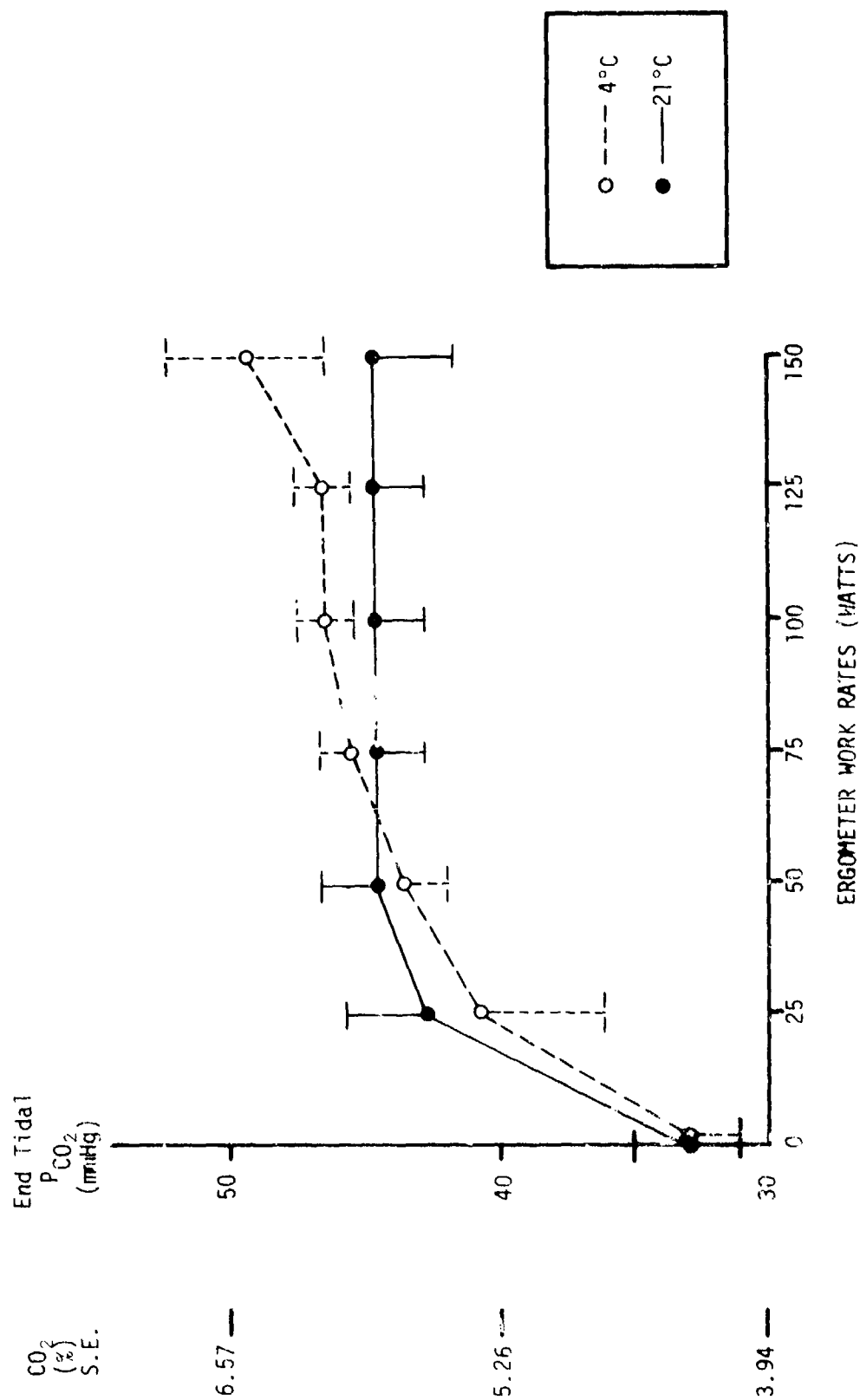


Figure 18. End Tidal  $P_{CO_2}$  Versus Work Rate for Graded Exercise for All Subjects;  
 $P_{O_2}$  1.76 ata and 21°C (70°F) and 4°C (39°F) Water.

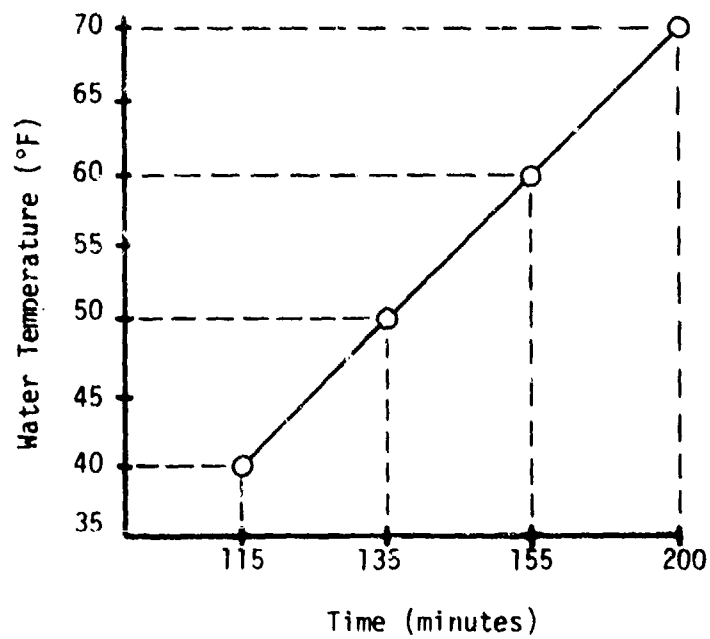


Figure 19. Operational Limits for Use of the Modified Draeger LAR V at 25 FSW

While figure 19 defines the operational limits of the LAR V hardware at 25 FSW, it does not define the established oxygen diving limits in the U.S. Navy. These limits are presently determined by table 13-1 of the U.S. Navy Diving Manual.

#### REFERENCES (PART II)

4. Lambertsen, C.J., J.H. Ewing, R.H. Rough, R. Gould, and M.W. Stroud (1955). Oxygen Toxicity. Arterial and Internal Jugular Blood Gas Composition In Man During Inhalation of Air, 100% O<sub>2</sub> and 2% CO<sub>2</sub> at 3.5 Atmospheres Ambient Pressure, J. Appl. Physiol. 8:255-263.
5. James, T.W. (1976): Modified Collins Pedal Mode Ergometer, Development and Medial Tests, U.S. Navy Experimental Diving Unit Report 1-76.
6. Thalmann, E.D., D.K. Sponholtz, and C.E.G. Lundgren (1978): Chamber Based System for Physiological Monitoring of Submerged Exercising Subjects, Undersea Biomed. Res. 5:293-300.
7. Smith, J.G. (1973): Low Temperature Performance of CO<sub>2</sub> Scrubber Systems: Proceedings of the 1973 Diver's Gas Purity Symposium.